



Form Agro-Waste to Bio-Resources: Innovative Extraction of Banana Pseudostems Fibre

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ABSTRACT

Banana is one of the most widely cultivated crops in tropical and subtropical regions, and its cultivation generates a significant amount of agricultural waste in the form of banana pseudostems after fruit harvesting. The extraction of fibre from banana stem offers an effective and sustainable solution for waste management while contributing to eco-friendly material development. Banana fibre is a natural, biodegradable, renewable, and cost-effective lignocellulosic fibre with high cellulose content, good tensile strength, and excellent moisture absorbency. The process of banana fibre extraction typically involves mechanical decortication of the pseudostem, followed by washing and drying to remove non-fibrous materials. Additional chemical or enzymatic treatments may be applied to improve fibre purity, flexibility, and durability depending on the intended application. These extraction methods require relatively low energy input and can be adapted for small-scale rural operations, making them suitable for decentralized production systems. The extraction of fibre from banana stem represents a sustainable and environmentally responsible approach to agricultural waste utilization. It contributes significantly to resource efficiency, pollution reduction, and the development of green materials. Promoting banana fibre extraction and its applications can play a vital role in achieving sustainable development goals related to responsible consumption, climate action, and rural development. In this paper Banana waste can be turned into useful fibre, offering a sustainable solution for waste management and eco-friendly materials. The fibre is natural, strong, and absorbent, with a simple, energy-efficient extraction process.

Keywords: Bannana pseudostems fibres, chemical treatment, Cellulose, FTIR Analysis

INTRODUCTION

The growing concern over environmental pollution, depletion of non-renewable resources and accumulation of synthetic waste has intensified globe interest in sustainable and biodegradable materials. Natural fibres have emerged as promising alternatives to synthetic fibres due to their renewability, biodegradability, low cost and minimal environmental impact. Plant-based fibres in particular are gaining significant attention in scientific research because of their high cellulose content, good mechanical strength and wide range of applications in textile, biomedical products and environmental remediation. India

contributes approximately 30–35% of the world's plant-based natural fibre production (mainly cotton, jute, banana fibre, and coir), followed by China with about 20–25%, Bangladesh with around 7–10% (primarily jute), and Brazil with nearly 5–7%. In India, banana fibre productivity is high due to the country's large banana cultivation area and abundant availability of pseudostems as agricultural waste. India produces nearly 35 million tonnes of bananas annually, generating about 30 million tonnes of pseudostem biomass, from which fibre is extracted after harvesting.

Studies and reports from the National Research Centre for Banana (NRCB) indicate that approximately 400–600 kg of banana fibre can be obtained per hectare of banana cultivation, depending on variety and extraction method. This translates to an estimated 1.5–1.8 million tonnes of potential banana fibre production per year, making India the world's most significant source of banana fibre. The high productivity, combined with low raw-material cost and biodegradability, positions banana fibre as an important sustainable resource for textiles, biocomposites, paper, and hygiene products in India. Bananas are widely cultivated in tropical and subtropical regions and rank as the fourth most important fruit crop globally. After harvesting, large quantities of banana pseudostem residue are left in the field, generating several tons per hectare annually, which are often used as organic matter or energy sources. These residues have gained attention as a valuable source of natural fibres for applications such as pulping and composite materials. Natural materials have gained significant attention in manufacturing sectors due to increasing ecological concerns (Baley *et al.*, 2005).

In recent years, natural fibre have been proven to be a practical alternative to non-renewable, abrasive, and costly synthetic fibres (Bourmaud *et al.*, 2010; Osorio *et al.*, 2012). These fibres offer several advantages, including biodegradability, renewability, wide availability, low density, reduced cost, high tensile strength, and good stiffness. Such properties make them suitable for the development of lightweight, eco-friendly structural composites (Reddy *et al.* 2013). Structurally, banana fibre is composed of cellulose, hemicellulose, and lignin, giving it high tensile strength, durability, and moisture absorbency. Its

lightweight nature and natural absorbent properties make it an excellent candidate for applications in hygiene products such as diapers and sanitary pads (Sathishkumar *et al.*, 2013). Moreover, banana fibres natural antibacterial properties and breathability enhance its suitability for skin-contact materials, reducing irritation and promoting comfort (Kumar *et al.*, 2015).

Consequently, extensive research efforts have focused on the utilization of natural fibers as reinforcement materials in polymer composites for applications in aerospace, automotive, electronics, and medical industries (Sreenivasan *et al.*, 2011b; Khan *et al.*, 2013). Banana plant fibres obtained from the pseudostem, fruit stalk and leaves exhibit physical strength and cellulose content comparable to other commercial fibrous by-products, making them an environmentally friendly. The presence of non-cellulosic components and impurities can negatively affect fibre performance, necessitating suitable extraction and treatment methods. Various mechanical, chemical, enzymatic, and combined treatments have been explored, with alkaline chemical treatment being widely used due to the differing stability of cellulose and non-cellulosic components, allowing effective fibre extraction and property enhancement (Xu *et al.* 2015).

Table 1: Banana fibre properties (Ali and Karale, 2022)

Fiber properties	
Tenacity	29.98g/denier
Fineness	17.15Denier
Moisture Regain	13.00%
Elongation	6.54
Total cellulose	1.70%
Alpha cellulose	81.80%
Residual Gum	41.90%
lignin	15.00%

The FTIR spectral analysis reveals strong characteristic cellulose peaks (3400, 2890, 1160, 1050, 1025, 897 cm^{-1}) and the suppression or disappearance of hemicellulose (1730 cm^{-1}) and lignin (1600–1510 cm^{-1}) peaks. This confirms that the acid-alkali pulping and peroxide treatment effectively removed non-cellulosic components, yielding high-purity cellulose.

Table 2: FTIR Peak Assignments and Interpretation of Treated Banana Pseudostem Cellulose

Observed Peak (cm ⁻¹)	Functional Group / Vibration	Assignment	Interpretation / Significance
3300–3400	O–H stretching (hydrogen-bonded)	Hydroxyl groups in cellulose	Confirms cellulose presence; indicates extensive hydrogen bonding typical of cellulose I.
2890–2920	C–H stretching	CH and CH ₂ groups of glucopyranose ring	Indicates polysaccharide backbone of cellulose.
1730 (Absent/Very Weak)	C=O stretching	Acetyl/uronic ester groups of hemicellulose	Absence of this peak indicates removal of hemicellulose.
1600–1510 (Weak/Reduced)	Aromatic skeletal vibrations	Lignin (benzene ring)	Very weak intensity confirms significant delignification.
1425–1430	C–H scissoring	Crystalline cellulose	Indicates the presence of crystalline cellulose I structure.
1365	C–H bending	Cellulose	Confirms characteristic C–H bending vibration of purified cellulose.
1320–1315	C–H wagging	Cellulose	Relates to crystalline cellulose structure.
1270–1240	C–O stretching	Residual hemicellulose/lignin (usually)	Very weak intensity shows minimal non-cellulosic content.
1160	Asymmetric C–O–C stretching	β-1,4-glycosidic linkage	Confirms cellulose backbone integrity.
1105	C–O stretching	Polysaccharide ring vibrations	Strong intensity typical of cellulose.
1050	C–O–C ring	Pyranose ring of cellulose	Confirms intact cellulose monomeric structure.
1025	C–O stretching	Cellulose backbone	Indicates high cellulose content.
897	β-glycosidic C–H deformation	β-1,4 linkages of cellulose	Marker peak confirming cellulose I; indicates good purification.

MATERIAL AND METHODS

Collection of samples:

The raw materials required for the development of the biodegradable diaper prototype were collected from multiple verified sources. Fresh banana (*Musa spp.*) pseudostems were obtained from an agricultural field located in Dhakephal, near chh. sambhajinagar city Maharashtra.

Extraction of Banana Pseudo-stem Fibers

The fresh pseudostem was separated into individual sheaths manually. Extraction of banana fiber which was done manually using shredding machines. Extracted fiber are washed thoroughly with clean water. Fiber is sundried for 6-8hours.

Chemical Treatment:

The banana pseudostem fiber involves sequential acid and alkali treatments to remove non-cellulosic components and enhance cellulose purity. The 10g dried strips were immersed in 200mL of dilute sulfuric acid solution (7g/L). the mixture was heated in a water bath at 55°C for 2Hr to remove surface impurities, waxes, amorphous cellulose, and

hemicellulose, while also weakening hydrogen bonds and loosening the fiber structure. After thorough washing with distilled water to eliminate excess acid, the fiber immersed in 200mL of a liquid mixture composed of 7g/L H₂O₂, 3wt% Sodium carbonate at 95°C for 1.5hr to remove hemicelluloses and lignin. The sample was immersed in 200mL of 9g/L NaOH solution at boiling temperature for 3hr for further removal of hemicelluloses and lignins and then washed with 2g/L sulfuric acid solution to neutralize the residual alkali in the sample. Using a paper mould the mixture was then shaped into thin sheet and were allowed to sundry for 12 to 15 hr. (Xu et al.,2015)

**Fig. 1 Extraction process of banana fibre**

Characterization and mechanical properties:

Physical Appearance of banana fiber after mercerization:

The extracted banana fibres were initially washed with distilled water to remove adhering contaminants and air-dried at ambient temperature. Mercerization was performed by immersing the fibres in an aqueous sodium hydroxide solution (5–10% w/v) at room temperature for 2–4 h with intermittent agitation to ensure uniform alkali penetration. Following alkali treatment, the fibres were extensively washed with distilled water until the effluent attained neutral PH. Residual alkali was neutralized by rinsing the fibres with dilute acetic acid, followed by repeated washing with distilled water. The mercerized fibres were subsequently oven-dried at 60 °C to constant mass and stored in a desiccated environment for further characterization. Alkali-treated fibres exhibited a reduction in surface impurities and non-cellulosic constituents, resulting in enhanced surface roughness, increased porosity, and improved fibre flexibility, which are desirable for downstream functional and structural applications.

Confirmation Test for cellulose:

Confirmation of cellulose was done by Schulze's reagent. Dissolve 40g of zinc chloride in 20ml of water, then dissolve 1.15g of iodine and 4.5 g of potassium iodide in 100ml of water. the two solutions, adding 1.5-2ml of water, shake well, let it settle and filter it. Then 1g of banana fiber sample was dried, finely cut and mount on clean glass slide. For pure cellulose power was used as a positive control and sodium carbonate was used as negative control. A few drops of freshly prepared Schultze's reagent were added. The compound was considered positive if a blue-violet color was produced (Lestari et al., 2025).

ATR-FTIR Spectroscopy:

Attenuated Total range transform infra-red (ATR-FTIR) Spectrometer. The determined chemical functional groups in the fibers. The scans were in the range of 400–4000 cm^{-1} with a resolution of 4 cm^{-1} (Twebaze et al., (2022).

RESULTS

The sequential mechanical and chemical treatment of banana pseudostem resulted in the successful extraction of purified cellulose-rich banana fibres.

Manual separation of the pseudostem sheaths followed by shredding produced continuous fibres, which after washing and sun-drying (6–8 h) exhibited a light brown appearance with reduced surface impurities. Acid pretreatment using dilute sulfuric acid (7 g/L) at 55 °C for 2 h effectively removed surface waxes, pectic substances, and a portion of amorphous cellulose and hemicellulose. This treatment caused partial disruption of hydrogen bonding within the fibre matrix, leading to fibre swelling and improved accessibility for subsequent chemical treatments. The treated fibres appeared cleaner and more flexible compared to untreated fibres. The combined oxidative-alkaline treatment using hydrogen peroxide (7 g/L) and sodium carbonate (3 wt.%) at 95 °C for 1.5 h resulted in significant delignification and hemicellulose removal. A noticeable change in fibre color from brown to pale yellow was observed, indicating effective lignin degradation. The fibres also showed improved separation and smoothness, suggesting enhanced fibrillation. Further alkali treatment with sodium hydroxide (9 g/L) at boiling temperature for 3 h led to extensive removal of residual hemicellulose and lignin components.

This mercerization process increased fibre whiteness, reduced fibre diameter, and enhanced surface roughness due to fibril exposure. Neutralization with dilute sulfuric acid (2 g/L) stabilized the fibres and prevented alkali-induced degradation. The final processed fibres were easily dispersed in water and successfully formed into uniform, thin sheets using a paper mould. After sun drying for 12–15 h, the sheets exhibited good structural integrity, uniform thickness, and improved mechanical cohesion, indicating effective fibre bonding. (table no. 3)

Table 3: Physical Appearance of banana fiber

Sr. no.	Physical Parameters	Observation
1	Color	Light cream to pale brown
2	Texture	Soft, flexible, and smooth
3	Structure	Clearly separated and uniformly combed fibers.

Confirmation Test for cellulose: The appearance of blue-violet coloration in the banana fibre sample, comparable to the cellulose standard, confirmed the presence of cellulose in the fibre. The absence of such coloration in the negative control validated the specificity of the test.



Fig.2 Banana fiber extraction



Fig.3 Banana fiber sheet

FTIR Spectra Analysis: The FTIR spectrum of the chemically-treated banana pseudostem fibre exhibits characteristic absorption bands that confirm the presence of cellulose as the major component, while also indicating the effective removal of hemicellulose and lignin during the acid-alkali pretreatment process.

The FTIR spectral analysis reveals strong characteristic cellulose peaks (3400 , 2890 , 1160 , 1050 , 1025 , 897 cm^{-1}) and the suppression or disappearance of hemicellulose (1730 cm^{-1}) and lignin (1600 – 1510 cm^{-1}) peaks. This confirms that the acid-alkali pulping and peroxide treatment effectively removed non-cellulosic components, yielding high-purity cellulose. The FTIR analysis conclusively shows that the sample obtained after the sequential acid-peroxide-alkali treatment of banana pseudostem fibres is highly enriched cellulose. The key cellulose functional group peaks remain prominent, while hemicellulose and lignin peaks are significantly diminished or absent.

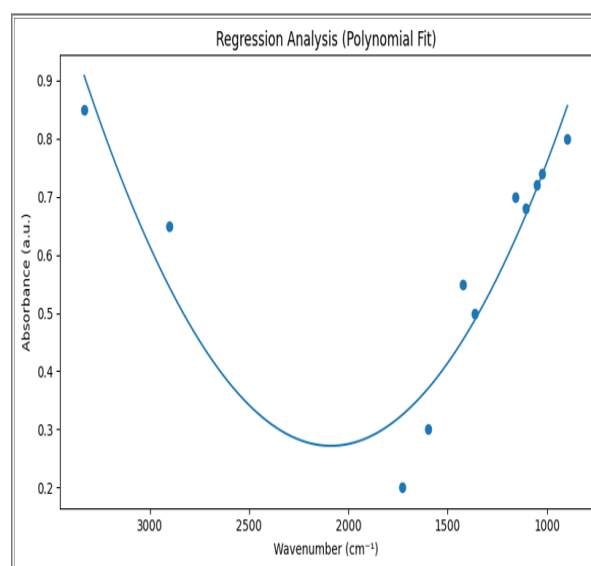


Fig. 4. FTIR Analysis of banana fibres

1. Cellulosic Structure: Broad O-H stretch (3300 – 3400 cm^{-1}) indicates cellulose with hydrogen bonding.
2. Cellulose Backbone: C-H stretch (2890 – 2920 cm^{-1}) present.
3. Hemicellulose Removal: Absent carbonyl peak (~ 1730 cm^{-1}).
4. Lignin Removal: Weak/absent aromatic peaks (1510 – 1600 cm^{-1}).
5. Cellulose Fingerprint: Peaks at 1160 , 1105 , 1050 , 1025 , 897 cm^{-1} confirm cellulose I structure.

In this present paper banana waste can be turned into useful fibre, offering a sustainable solution for waste management and eco-friendly materials. The fibre is natural, strong, and absorbent, with a simple, energy-efficient extraction process

CONCLUSION

In this present paper banana waste can be turned into useful fibre, offering a sustainable solution for waste

management and eco-friendly materials. The fibre is natural, strong, and absorbent, with a simple, energy-efficient extraction process. The presence of cellulose in banana fibre is confirmed by the blue-violet coloration, matching the cellulose standard. This indicates successful cellulose extraction, supporting the fibre's potential for various applications. The Cellulosic Structure: Broad O-H stretch ($3300\text{--}3400\text{ cm}^{-1}$) indicates cellulose with hydrogen bonding. Cellulose Backbone: C-H stretch ($2890\text{--}2920\text{ cm}^{-1}$) present. Hemicellulose Removal: Absent carbonyl peak ($\sim 1730\text{ cm}^{-1}$). Lignin Removal: Weak/absent aromatic peaks ($1510\text{--}1600\text{ cm}^{-1}$). Cellulose Fingerprint: Peaks at 1160, 1105, 1050, 1025, 897 cm^{-1} confirm cellulose I structure. The FTIR analysis confirms the extracted banana fibre is highly purified cellulose, with minimal lignin and hemicellulose. Sequential acid-peroxide-alkali treatment effectively purified the fibre, enhancing its cellulose content.

Conflict of interest

The authors declare no competing interests.

Data Availability Statement: Not applicable.

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